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COMMISSIONING OF THE RELATIVISTIC HEAVY ION COLLIDER*

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Abstract

This report describes in detail steps performed in bringing the Relativistic Heavy Ion Collider (RHIC) from the commissioning into the operational stage when collisions between 60 bunches of fully striped gold ions, were routinely provided. Corrections of the few power supplies connections by the beam measurements are described. Beam lifetime improvements at injection, along the acceleration are shown. The beam diagnostic results; like Schottky detector, beam profile monitor, beam position monitors, tune meter and others, are shown [1].

1 INTRODUCTION

RHIC consists of two separate superconducting rings built with possibilities of colliding unequal species (between polarized protons and gold ions) up to the energies of 100 GeV/nucleon. The accelerator is with three-fold symmetry, with two large detectors, STAR and PHENIX located at 6 and 8 and PHOBOS, and BRAHMS at 10 and 2 o'clock. The design luminosity is $L = 2\ 10^{26}$ $cm^{-1}\ s^{-1}$ with 56 bunches in both rings, filling 60 of 360 available buckets.

Table 1: Parameters and performance goals for RUN2000

Injection Energy	γ=10.27 E=9.57 GeV/n
Storage Energy	γ=70.00 E=65.1 GeV/n
Bunch intensity	$0.5\ 10^9$
Number of bunches	56
Transverse Emittance	15 π mm mrad Normalized 95 %
Longitudinal Emittance	0.3 eV s Per nucleon per bunch
β^* @ IP	3m @ 2, 4, 8, 12 8 m @ 6 and 10 o'clock
Luminosity	$2\ 10^{25}\ cm^{-2}\ s^{-1}$ 10% of the design
Integrated Luminosity	few μb^{-1}

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This report describes major steps in RHIC commissioning during the summer of 2000. In the first part few major commissioning challenges are described. The most important results, from few RHIC systems, are shown in the next section. Next, bringing beams from two separate "blue" and "yellow" rings, into collisions and stores of gold ions are described. In the summary part necessary steps and commissioning of additional systems during the next RHIC-2001 run are mentioned. Basic parameters of the previous RHIC RUN2000 are presented in Table 1.

2 COMMISSIONING CHALLENGES

2.1 Injection

Fully stripped gold ion beams Au^{79+} were injected into both blue and yellow rings from the AGS with energy of 9.57 GeV (in Table 1). Orbits in both rings were successfully corrected with a *rms.* value of less than few millimeters. The betatron tune measurements had shown unexpected sensitivity to momentum at the beginning of commissioning. The initial measured chromaticities were quite different from the model predictions, due to a larger sextupole multipole component in dipoles. A control of the power supplies and excitations of all magnets in RHIC has a direct correspondence between the "model" of the accelerator and actual settings. Additional correction for 60 units of chromaticity was necessary to compensate for the larger values of the sextupole multipole within the dipoles. Very precise and reliable beam position monitors were available early on in the commissioning effort allowing beam-based diagnostics to detect hardware problems. They also demonstrated excellent agreement between measured, and accelerator model predictions. With a help of *on-line model* by comparisons with measured data, a wrong polarity of a shunt quadrupole power supply was found as illustrated in Fig.1. This search was obtained by comparison of the dispersion functions. The global orbit correction was able to reduce orbit offsets of the order of a millimeter. An example of the orbit correction is shown in Figure 2. The orbit correction program receives information from the BPM system, calculates corrections and communicates with the ramp manager. It sets the correction magnets to new values. The correction was a part of the preparations for ramping to high energy. Before any start of the ramp, the sequencer checked and set required values for different systems like RF, tune meter etc.

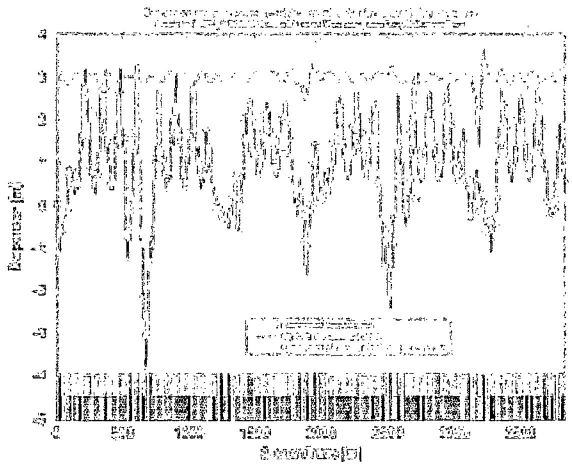

Figure 1: Comparison between measured dispersion and the model where the Q89 power supply was reversed.

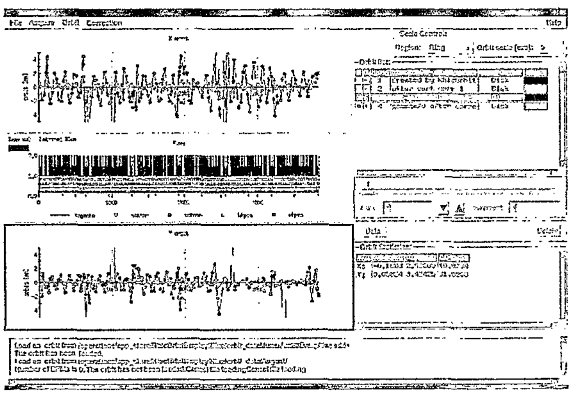

Figure 2. An example of orbit correction in the Blue ring is presented in Figure 4. The red color data are corrected while the blue color data are the orbits before corrections.

Injected bunched were captured by digitally controlled synchronization between the AGS and RHIC RF systems. The whole RF system performed very reliably and the accelerating cavities were fully commissioned. Their high voltage status was connected to the permit link.

2.2 Persistent current effect

The *snap back* and *persistent current* effects were additional concerns, which were measured and compared to predicted values (see Fig. 3). The effect of the persistent currents was clearly visible at the injection [2]. The lifetime of bunches injected in a sequence was steadily improving in time within first few minutes. A comparison between predicted and measured differences of the chromaticity, due to a time dependence of the sextupole multipole in dipoles showed an excellent agreement (Fig. 3).

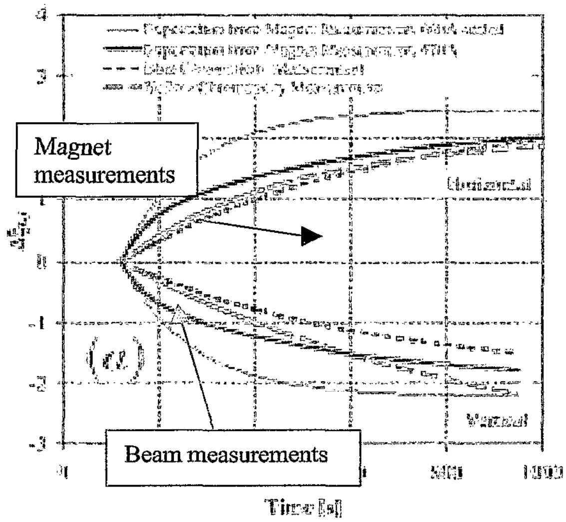

Figure 3. Persistent current effect: a comparison between a time dependence of beam measured chromaticity with a change of chromaticity obtained by time dependence in magnetic field measurements of sextupole component in dipoles.

2.3 Acceleration

Unfortunately, RHIC is the first superconducting, slow ramping accelerator that crosses transition energy during acceleration. Although some beam loss and longitudinal emittance growth was observed from crossing transition energy, the effect was not excessive due to still lower beam intensity and a favorable lattice functions. The second order momentum dependence coefficient α_1 was measured to be α_1=-1.5 due to the lattice functions. It minimized momentum dependent (chromatic) effects at transition.

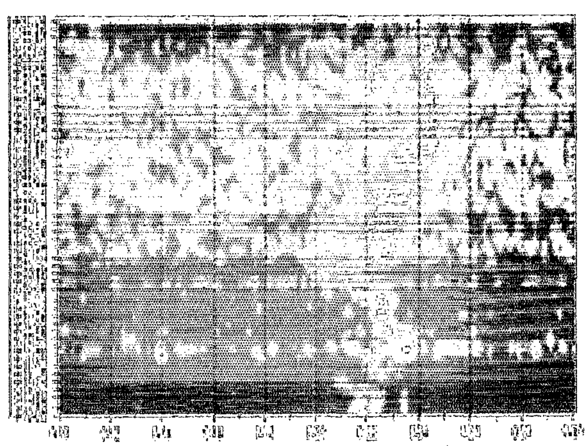

Figure 4. Horizontal betatron tunes along the RHIC acceleration.

To accommodate easier transition crossing a first order γ_t jump was designed and built. Due to still missing power supplies, during the RHIC RUN2000, the transition crossing had to be performed by the RF radial loop jump. To avoid the beam loss it was important to keep the partial tunes between 0.2 and 0.25 during acceleration as shown in Fig. 3 by the tune measurements.

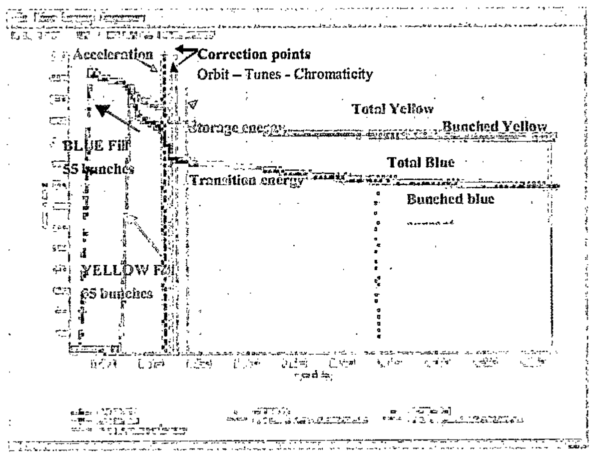

Figure 5. Typical ramp during the RHIC RUN2000 is shown in Fig. 5.

The acceleration cycle is shown in Fig. 5. Fifty-six bunches were filled one ring with a lifetime larger than 30 minutes.

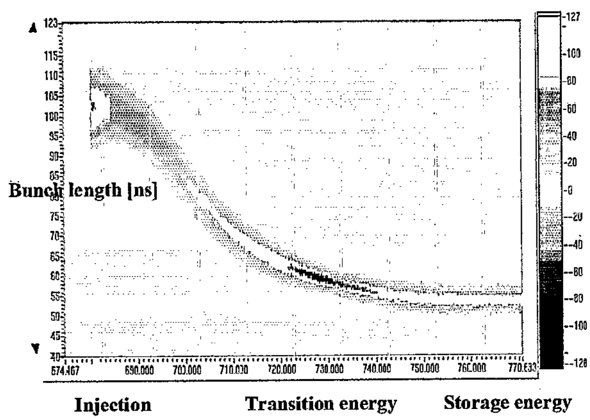

Figure 6. Wall current monitor along the accelerating ramp in RHIC.

The other ring was filled by a change of polarity of the switching magnet in the beam line from AGS to RHIC (ATR). During the acceleration cycle the wall current monitors in both rings were recording the longitudinal profiles as presented in Figure 6.

3 ESTABLISHING COLLISIONS

At the end of the acceleration cycle two beams were first longitudinally brought by cogging into collisions with help of a wall current monitor located at the interaction point at 4 o'clock. The collision rate was measured using identical Zero Degree Calorimeters (ZDC) at all four interaction regions. The ZDC counters detect at least one neutron on each side from mutual Coulomb and nuclear dissociation with a total cross section of 10.7 barns at 65 GeV beam energy. The peak luminosity for the initial rate shown in Fig. 7 is then 3.3 10^{25} cm^{-2} s^{-1} for BRAHMS and the average luminosity for the store was 1.7 10^{25} cm^{-2} s^{-1}. Independent determination of the luminosity using Vernier scans gives a cross section for the ZDC counts of 9.1.8 barns, which is consistent with the results given above.

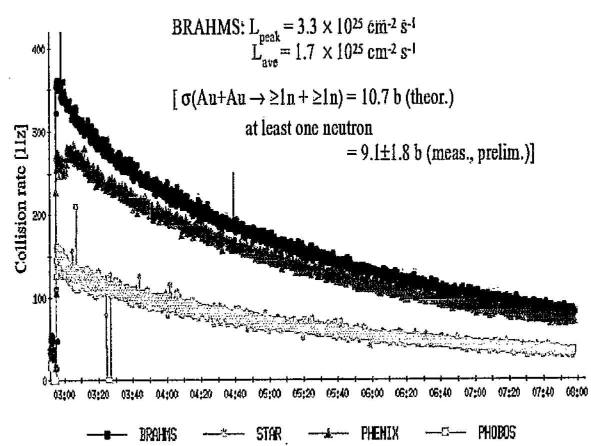

Figure 7. Luminosities at all four experiments measured by the Zero-degree calorimeters.

4 SUMMARY

RHIC RUN2000 commissioning and first operation was very successful. Full design luminosity with gold ions, and collisions with polarized protons are planned for RUN2001. Other systems to be commissioned in the next run are: Phase Lock Tune Feedback, γ_t transition jump, storage cavities (will make short bunches), β squeeze with all power supplies installed, and the bent crystal channeling collimation.

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